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Solutions for Our Climate

° Report

# The Climate Crisis— Culprits and Liability

## Contribution of South Korea's Top Ten Emitting Corporates to Climate Loss & Damage

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# The Climate Crisis—Culprits and Liability:

## Contribution of South Korea's Top Ten Emitting Corporates to Climate Loss & Damage


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| Publication Date | **August 2025** |
| Authors | **Soyeon Lim \| Jeongho Jo** |
| Contributor | **Haewon McJeon** |
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Solutions for Our Climate (SFOC) is an independent nonprofit organization that works to accelerate global greenhouse gas emissions reduction and energy transition. SFOC leverages research, litigation, community organizing, and strategic communications to deliver practical climate solutions and build movements for change.

# Table of Contents

# Introduction

The climate crisis is no longer a distant possibility but a present threat and harsh reality. Climate disasters—heatwaves, torrential rains, droughts, and wildfires—have become part of daily life, inflicting severe damage across societies and economies. Yet debates on responsibility for greenhouse gas (GHG) emissions and the climate crisis have remained largely on the national level. Until recently, few studies directly linked individual corporations' emissions to climate loss and damage. Now, the emerging concept of carbon liability has gained traction in global scholarship, spurring efforts to quantify the climate impacts of cumulative corporate emissions and pushing the boundaries of the carbon liability discourse in the legal and financial spheres. A landmark example is the Nature publication by Callahan and Mankin (2025). The study establishes the connection between corporate GHG emissions and climate disasters and translates them into measurable economic losses and potential compensation. Building on their approach, this study applies the methodology to South Korea's ten largest corporate emitters, quantifying their contributions to heatwave-related losses from past emissions and projecting future losses under two mitigation scenarios for 2025–2050—offering a data-driven basis for the question: Who is responsible, and how much should each entity be held liable?

# Executive Summary

This study applies the methodology from Callahan and Mankin (2025) to **quantify heatwave-related economic losses attributable** to South Korea's ten largest corporate emitters, drawing on their historical emissions (2011–2023) and modeled scenarios for the future (2025–2050).

Based on historical data from 2011–2023, the cumulative emissions from the ten corporate emitters are estimated at approximately 4.1 billion $tCO_2$-eq (43.5 percent of the national total for the same period). The resulting heatwave-related losses are valued at USD 119.6 billion (approx. KRW 161 trillion). POSCO alone accounts for USD 28.1 billion (approx. KRW 38 trillion), while the five KEPCO-affiliated power generators together represent USD 72.9 billion (approx. KRW 98 trillion). **These figures provide empirical evidence of the scale of corporate accountability for GHG emissions and their contributions to losses.**

Under a Current Policy (CurPol) trajectory, cumulative losses are projected at USD 518.9 billion (approx. KRW 700 trillion). By contrast, Net Zero pathway, could keep losses to USD 204.7 billion (approx. KRW 276 trillion), avoiding an estimated USD 314.2 billion (approx. KRW 424 trillion) in damages. **The implication is clear: net-zero policies are not optional add-ons but an essential cornerstone.** Failure to pursue carbon neutrality will lead to escalating economic and social costs.

Because this analysis considers only heatwave events, the true scale of damage would be far greater if floods, droughts, wildfires, and other hazards were included. **By providing scientific evidence that links individual corporate emissions to quantifiable losses**, this study **offers a compelling case for establishing practical emissions reduction frameworks at both the national and corporate levels.**

# Key Findings

## 1. Past Loss Contributions (2011–2023)

- Top Ten Corporate Emitters: Cumulative emissions of approx. 4.1 billion $tCO_2$-eq and contribution to heatwave-attributable loss of USD 119.6 billion (approx. KRW 161 trillion)
- Emissions from the top ten emitters account for 43.5 percent of the domestic total during the same period.

## 2. Future Loss Projections (2025–2050)

- Potential reductions in cumulative emissions: approx. 10.8 billion $tCO_2$-eq
- Avoidable losses: approx. USD 314.7 billion (approx. KRW 424 trillion)
- Avoidable losses by top ten emitters: approx. USD 136.6 billion (approx. KRW 184 trillion)

## 3. Limitations and Expandability

- The loss coefficient $\alpha_{1990}$ (USD 29.07 /tonne; on the basis of cumulative emissions since 1990) is applied, and the analysis was confined to heatwaves only, thus restricting the scope of estimated losses.
- The magnitude of losses would soar if the $\alpha_{1850}$ loss coefficient (based on cumulative emissions since 1850), which is approximately 1.5 times the value of $\alpha_{1990}$, were applied and other climate impacts such as floods, droughts, and wildfires were also factored in.

## 4. Conclusion and Insights

- To proactively address the climate crisis, a more inclusive principle of carbon liability that goes beyond the national level to consider corporations and a practical reduction implementation framework should be established.

# 1 Background

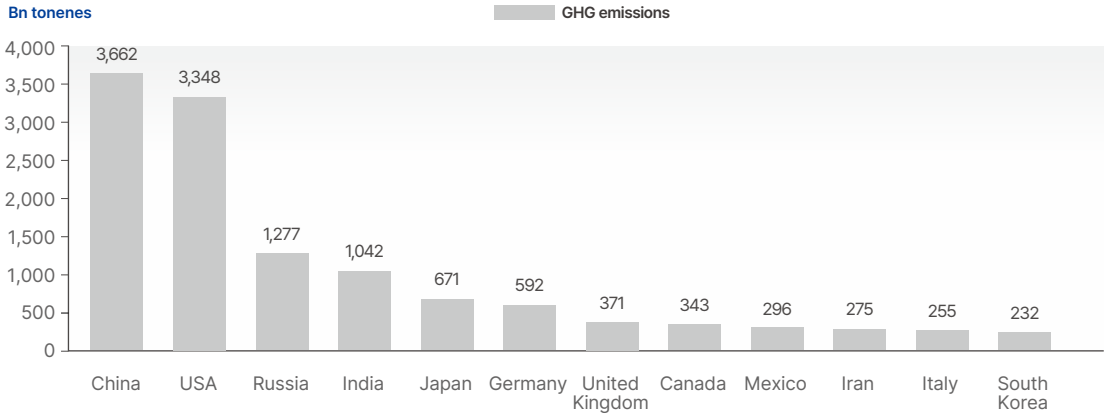
Climate disasters are no longer exceptional; they are now part of daily life. They haunt us in various forms, including heatwaves, wildfires, and floods all over the planet, and the damage they cause is increasing at an alarming rate. In the early spring of 2025, wildfires broke out in many parts of South Korea—Gyeongsangnam-do and Gyeongsangbuk-do Provinces, Ulsan Metropolitan City, Chungcheongbuk-do Province, and Jeollabuk-do Province—leaving the greatest wildfire damage in history, revealing new dangers of wildfires in winter and spring.[1] In the summer of 2025, southern Europe endured unprecedented heatwaves. Temperatures in El Granado hit 46 degrees Celsius, the highest in 60 years. According to the 2024 European State of the Climate (ESOTC) report jointly published by the World Meteorological Organization (WMO) and the Copernicus Climate Change Service, heat-related deaths in Europe have increased by about 30 percent over the past two decades.[2]

**[Table 1] Cumulative GHG Emissions by Country[3]**

| Country | 1970-2022 Cumulative Emissions ($tCO_2$-eq) | Liability (USD) |
|---|---|---|
| **China** | 366.2 billion | 15.86041242 trillion |
| **USA** | 334.8 billion | 14.49823815 trillion |
| **Russia** | 127.7 billion | 5.52975293 trillion |
| **India** | 104.2 billion | 4.51377862 trillion |
| **Japan** | 67.1 billion | 2.90597428 trillion |
| **Germany** | 59.2 billion | 2.56561506 trillion |
| **United Kingdom** | 37.1 billion | 1.60884137 trillion |
| **Canada** | 34.3 billion | 1.48537878 trillion |
| **Mexico** | 29.6 billion | 1.28370384 trillion |
| **Iran** | 27.5 billion | 1.19119339 trillion |
| **Italy** | 25.5 billion | 1.10504934 trillion |
| **South Korea** | 23.2 billion | 1.00680077 trillion |

**Source**: Data from the European Commission's EDGAR database

**[Figure 1] Comparison of GHG Emissions Across Countries**




While the damage caused by climate change is evident, the allocation of responsibility has remained unclear. In particular, within the United Nations Framework Convention on Climate Change (UNFCCC)—including the Kyoto Protocol (1997)[4] and the Paris Agreement (2015)[5]—responsibility for GHG emissions has been subjected to national-level management and reporting. By contrast, efforts to quantify emissions for individual corporates and to link climate-related damage to liability have remained relatively weak. This is because corporate emissions occur across different regions and countries, and scientific and legal hurdles remain in proving causal links between long-term cumulative emissions and climate disasters. Moreover, due to the active lobbying efforts of fossil fuel companies and the continued lack of transparency, attempts to trace or assign specific corporate liability have often been hindered. These persistent limitations are now gradually giving way, thanks to advances in scientific research and legal doctrines, opening the door to deeper discussions on *climate liability*.

In parallel, movements to hold parties accountable for such disasters—namely, *climate litigation*—are also gathering momentum. According to a 2024 report by the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science (LSE), in 2023 alone, 230 new cases of climate litigation were filed worldwide.[6]

A notable example is the lawsuit filed by a Peruvian farmer against the German energy company RWE.[7] Saúl Luciano Lliuya, a farmer living in Huaraz, a city at the foot of the Andes Mountains, went to court alleging that global warming accelerated the melting of a glacier-fed lake near his home, increasing the risk of floods; and that RWE was partially accountable for it. Lliuya sought damages of approximately

USD 17,000—representing 0.47 percent of the total cost for flood defenses—on the grounds that RWE had historically emitted 0.47 percent of global GHG emissions.

This case (*Luciano Lliuya v. RWE AG*) had gone through multiple trial and appellate proceedings in German courts until, in May 2025, the Higher Regional Court of Hamm, Germany, finally dismissed the claimant's direct claim for damages. The court, however, affirmed the existence of scientific and legal grounds for corporate emissions' contribution to the damage. The final ruling also pointed out that the harmfulness of GHG emissions had been scientifically clear since at least 1958, and by 1965, major emitters should have foreseen the risks. Hence, the court recognized companies' failure to take appropriate countermeasures despite the foreseeability of the climate crisis as a critical element of corporate liability.[8] This ruling is a significant turning point as it was the first case in which the court formally recognized that the emissions of individual companies can bear partial responsibility for specific disasters, thereby establishing an institutional framework where science and law intersect in subsequent climate loss litigation.A new phase in the climate liability discourse is taking shape, driven by efforts to scientifically substantiate causation between corporate emissions and specific climate disasters. The *scientification of climate liability*—the increasing integration of advanced climate science into the evidentiary backbone of concrete climate harms—is no longer spoken of only among environmentalists; it has become a central concern for academia and the legal community.

Amid this trend, Callahan and Mankin (2025) offers robust scientific grounds for the climate change dialogue and helps usher it into a new phase focused on imposing substantive legal and policy liability.[9]

They conducted a quantitative analysis of how the cumulative GHG emissions of the world's 111 largest fossil fuel companies—"*carbon majors*"—contributed to worldwide surges in extreme heat events and declines in GDP between 1991 and 2020. By translating each company's share of climate-related loss and damage—"*carbon liability*"—into measurable economic terms, they have provided practical applications across scientific, legal, and policy domains.

This report applies the methodology from Callahan and Mankin (2025) to South Korea's top ten corporate GHG emitters. First, it estimates the economic value of their 2011–2023 share of climate loss and damage and determines their contributions to climate change—especially heatwaves. Second, it compares two 2025–2050 scenarios—a Net Zero scenario vs. a Current Policy scenario—in terms of emissions as well as loss and

damage to project disparities in the long-term socioeconomic losses from corporate policies. Based on this, the report aims to move beyond the question of "how much has been emitted," and seeks to derive actionable figures by addressing "who is liable and for how much" and "how much greater will the losses be if we fail to start on the transition path right away."

# 2 Scientific Approach to Climate Liability

## 1 The Emergence of the Carbon Liability Discourse

"Carbon liability" is a concept for quantifying the contributions of carbon majors—companies and institutions that are heavy emitters of GHGs—to specific climate disasters such as heatwaves, floods, and wildfires, as well as for holding them legally and financially accountable in proportion to their impacts. This notion goes beyond mere ethical finger-pointing at major emitters. It paves a way for claims for damages over emissions-driven economic losses and provides a foundation for policy measures.

One of the seminal works advancing the science and quantification of carbon liability discussions is the latest study by Callahan and Mankin (2025). GDP losses from heatwaves are calculated based on each company's cumulative emissions to determine the magnitude of individual corporate liability. Their study visualized how companies have contributed to the economic losses brought by the climate crisis and proposed a new accounting framework for quantifying individual corporate *climate debt*.

The climate liability debate is becoming increasingly scientific and specific. At the forefront of this trend was the report on carbon majors by Heede (2013).[10] Heede shed light on the fact that 63 percent of the total global GHG emissions from the 1850s to 2010 had been from 90 fossil fuel companies and state institutions.[11] The study marks the first-ever attempt to specifically name those who were responsible for the climate crisis, and the findings have been used as scientific grounds in many climate lawsuits. The study by Callahan and Mankin (2025), which this study builds on, also quantified causal links between individual corporate emissions and damage.

In addition, the British Institute of International and Comparative Law (BIICL), in a 2023 report, systematically examined how *climate attribution science*—the field that assesses causal links between GHG emissions and their climate impacts—can inform discussions on legal liability.[12] The report illustrates the process for proving the extent to which emissions from corporations or governments have contributed to actual

climate disasters and outlines how the results of such analyses can be harnessed in court to substantiate causation. This pioneering study was widely acclaimed in both legal and scientific circles for introducing a framework that connects long-term cumulative emissions to economic losses, rather than focusing on discrete events such as heatwaves or floods in particular years.

As such, recent studies have been steering the carbon liability discourse towards a legal framework grounded in numbers and data, while demystifying the link between emissions and damage. This science-backed approach extends well beyond the courtroom: it informs policy design, guides corporate climate-risk disclosure, and shapes the architecture of emissions trading markets.

# 3 Methodology

## 1 The Callahan & Mankin (2025) Methodology: An Overview

In their *Nature paper* "Carbon majors and the scientific case for climate liability," Callahan and Mankin (2025) present a quantitative analysis of historical GHG emissions from 111 major fossil fuel companies across the globe in terms of their impacts on global temperature rise, the intensification of heatwaves, and national GDP losses.[13] The study is recognized as the first to employ an end-to-end approach—applying time series analysis on longitudinal data (i.e., data collected over an extended period)—to calculate the contributions of GHG emissions to actual climate events, particularly extreme heatwaves.

Data on cumulative emissions from the 111 companies for the period 1920–2020, covering Scope 1 (direct operations), Scope 2 (energy consumption), and Scope 3 (supply chains), with adjustments made for overlaps were extracted from the "Carbon Majors" database. Based on these emissions data, the team established three-phase causal links between emissions and losses, as illustrated below:

### ① Emissions → Rise in Global Mean Surface Temperature (GMST)

The researchers used FAIR climate model* to quantify each company's contribution to the rise in GMST attributable from its GHG emissions. The key point here is not merely that temperatures have risen, but the assumption that, in the absence of this company, temperatures would not have increased to this extent.

***FAIR (Finite Amplitude Impulse Response) model** is a leading simulation tool used to estimate the extent to which carbon dioxide and other greenhouse gases warm the Earth. This climate model provides a computational framework for projecting how much the planet's temperature would rise in response to a given volume of emissions.

### ② Rise in GMST → Intensification of Heatwaves (Tx5d)*

Pattern scaling was used to estimate the impacts of corporate contributions to the rise in GMST on extreme heatwaves—defined here as the mean temperature of the hottest five days of the year—in particular countries or regions.

***Tx5d** stands for the "maximum five-day mean daily maximum temperature," which in plain English refers to the hottest five-day stretch on record, calculated by averaging each day's highest temperature.

### ③ Heatwaves → GDP Losses

The effects of intensified heatwaves on agricultural productivity, labor capacity, and health were converted into an econometric loss function to calculate annual GDP losses by country.

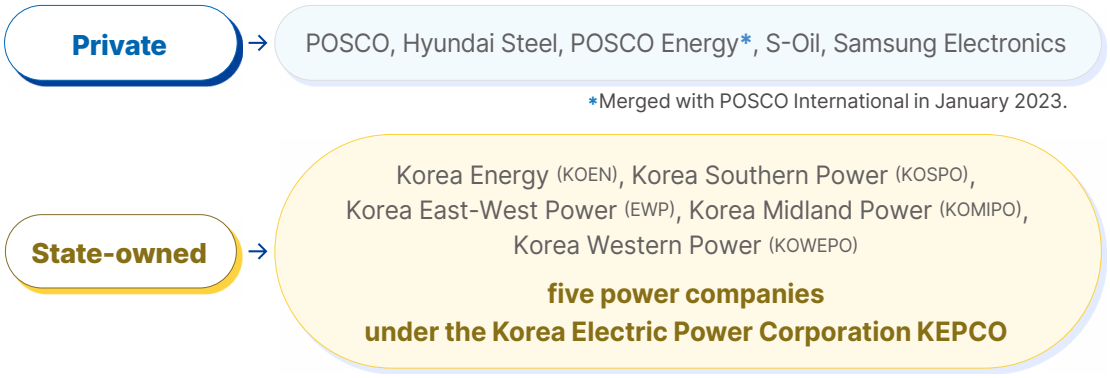
This analysis led the team to conclude that roughly USD 28 trillion in global GDP losses from heatwaves between 1991 and 2020 is attributable to the world's highest corporate emitters. Notably, the top five—Saudi Aramco, ExxonMobil, BP, Chevron, and Gazprom—accounted for about 35 percent of the total losses.

The study zeroed in on heatwaves alone in estimating losses, noting that this category of climate disasters has been proven to have the closest causal link to global warming. Total losses would have been even greater if other types of disasters—such as hurricanes, floods, droughts, sea-level rise, wildfires, and ecosystem disruptions—were factored in.

## 2 Application to South Korean Cases

Adopting the methodology from Callahan and Mankin (2025) to South Korea's major corporate emitters, this study estimated their respective shares of climate loss and damage based on their actual emissions and projected their potential emissions—and corresponding shares of climate loss and damage—under two future scenarios. Actual emissions data for Scope 1 and Scope 2 were taken from the 2011–2023 National Greenhouse Gas inventory disclosed by the Greenhouse Gas Inventory & Research Center of Korea and were then organized by company and by year.[14]

Two selection criteria were applied: ① highest emitting companies in 2023 and ② companies with publicly available emissions data. The following ten companies made their way onto the final list as a result.




Attributable losses per tonne of emissions were calculated using the methodology and findings of the referenced paper. The key elements related to the calculation of loss contributions are as follows:

> "If accounting begins in 1990, around the development of the scientific consensus on climate change, heatwave losses attributable to an actor contributing 5% of global emissions total $2.5 trillion (90% range: 1.05–4.47), contrasting with the $4.2 trillion (1.7–7.5) when counting from 1850."

Based on this, the loss contributions of individual companies are estimated as follows:

**Step. 1** Compilation of global cumulative GHG data during 1990–2020.

**Step. 2** Heatwave-related losses attributable to five percent of global emissions amount to USD 2.5 trillion for the entire period above, from which the loss per tonne ($\alpha_{1990}$) is derived.

**Step. 3** Loss contributions estimated by applying $\alpha_{1990}$ to their respective cumulative emissions of South Korea's top ten corporate emitters over the same period.

Based on this methodology, the per-tonne loss cost ($\alpha_{1990}$) is calculated at USD 29.07. While the referenced paper also presents a coefficient derived from emissions data reaching back to 1850 ($\alpha_{1850}$), this report uses $\alpha_{1990}$ in calculating loss contributions, given its international acceptance and its close alignment with South Korea's recent emissions time series. For reference, applying $\alpha_{1850}$—which extends back to the pre-industrial era—raises the coefficient by roughly a factor of 1.5.

From the datasets of the referenced report and made available through IEEE DataPort, this study drew on the global GHG emissions dataset to calculate total emissions.[15] Annual values for carbon dioxide ($CO_2$) from fossil fuel combustion (FFI) and methane ($CH_4$) were combined to obtain the aggregate. To ensure analytical consistency across gas types, all GHG emissions were converted into carbon dioxide equivalents ($tCO_2$-eq). Since the warming impact varies across GHGs, the Global Warming Potential (GWP) metric was applied to express each gas's warming effect relative to that of carbon dioxide.[16]

This study projects emissions for 2025–2050 under two pathways drawn from the government's carbon neutrality plans: a Net-Zero scenario and a Current Policy (CurPol) scenario. For each pathway, emissions were estimated in five-year increments, and using the same methodology, potential contributions to climate-related losses were calculated. These projections allow for a comparison of company-specific loss outcomes diverging depending on whether a low-carbon transition is delivered or deferred.

# 4 Analysis: Contributions of Historical Emissions to Climate Losses (2011–2023)

## 1 Emissions and Contributions by Company

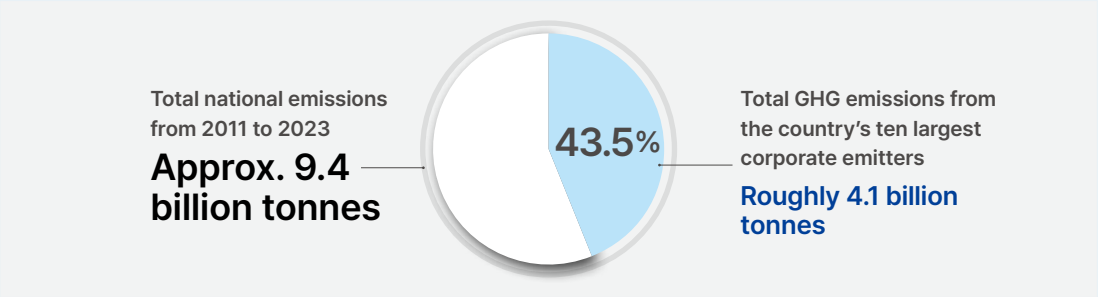
[Table 2] Annual GHG Emissions in South Korea (1990–2022) According to the 2006 IPCC Guidelines

| Year | Emissions ($tCO_2$-eq) | Graph |
|---|---|---|
| 1990 | 310.6 million | |
| 1991 | 341.2 million | |
| 1992 | 368.8 million | |
| 1993 | 406.8 million | |
| 1994 | 432.8 million | |
| 1995 | 464.5 million | |
| 1996 | 501.1 million | |
| 1997 | 526.1 million | |
| 1998 | 460.2 million | |
| 1999 | 500.6 million | |
| 2000 | 533.5 million | |
| 2001 | 550.8 million | |
| 2002 | 571.0 million | |
| 2003 | 584.5 million | |
| 2004 | 595.8 million | |
| 2005 | 594.4 million | |
| 2006 | 607.0 million | |
| 2007 | 613.6 million | |
| 2008 | 628.8 million | |
| 2009 | 632.7 million | |
| 2010 | 689.8 million | |
| 2011 | 721.6 million | |
| 2012 | 720.2 million | |
| 2013 | 728.4 million | |
| 2014 | 724.3 million | |
| 2015 | 726.1 million | |
| 2016 | 737.4 million | |
| 2017 | 759.6 million | |
| 2018 | 783.9 million | |
| 2019 | 759.4 million | |
| 2020 | 713.0 million | |
| 2021 | 741.0 million | |
| 2022 | 724.3 million | |

**Source**: Greenhouse Gas Inventory & Research Center of Korea

South Korea is a significant emitter. The country ranks 12th in the world for GHG emissions, releasing an estimated 20.3 billion tonnes between 1990 and 2022. Emissions peaked in 2018 at around 783.9 million tonnes. Recent years have seen them edging downward, but the 2022 total remained more than double the 1990 level. Global heatwave-related economic losses in Korea over the 1990–2022 period are estimated at USD 580 billion (approx. KRW 780 trillion) when the coefficient α1990 is applied to those emissions.

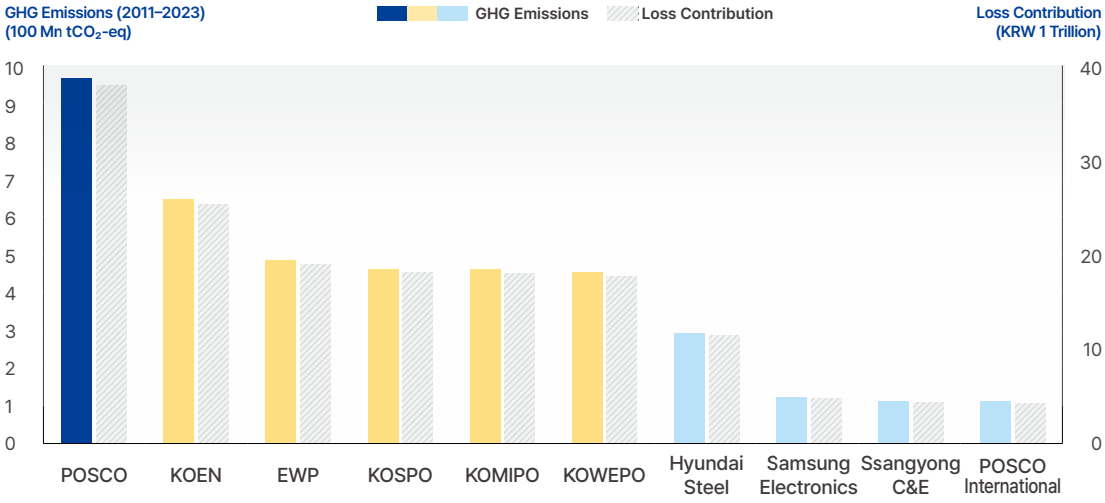
The country's ten largest corporate emitters cannot deny their disproportionate share of this burden. From 2011 to 2023, their GHG emissions reached nearly half the national total. Collectively, these corporates released roughly 4.1 billion tonnes of GHGs—43.5 percent of the total national emissions of 9.4 billion tonnes—during the same period. The economic losses attributable to their emissions over this 13-year period are estimated at around USD 119.6 billion (approx. KRW 161 trillion).



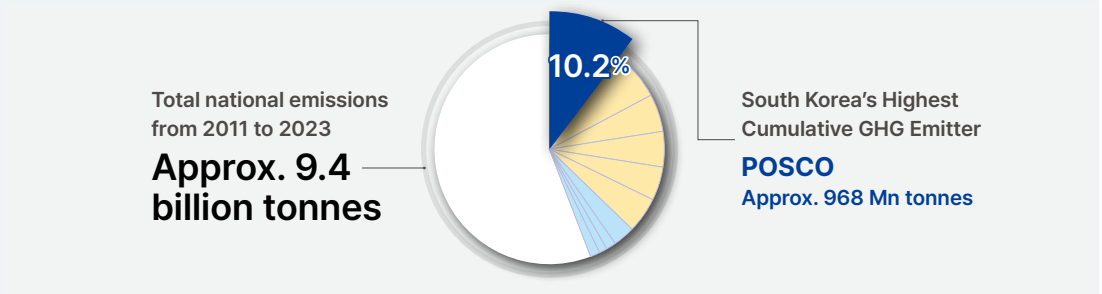

**[Table 3]** Cumulative GHG Emissions and Loss Contributions by South Korea's Top Ten Emitters (Including Five Subsidiaries of KEPCO)

| Company (incl. KEPCO) | | GHG Emissions 2011–2023 (tCO2-eq) | Loss Contribution (USD 100 Mn) | Loss Contribution (KRW 1 Tn) |
|---|---|---|---|---|
| POSCO | | 967.88 million | 281.3 | 37.9 |
| Including KEPCO's subsidiaries | KOEN | 646.85 million | 188 | 25.3 |
| | EWP | 485.89 million | 141.2 | 19 |
| | KOSPO | 460.76 million | 133.9 | 18.1 |
| | KOMIPO | 460.37 million | 133.8 | 18 |
| | KOWEPO | 453.22 million | 131.7 | 17.7 |
| Hyundai Steel | | 293.18 million | 85.2 | 11.5 |
| Samsung Electronics | | 123.71 million | 35.9 | 4.8 |
| Ssangyong C&E | | 112.75 million | 32.7 | 4.4 |
| POSCO International | | 111.99 million | 32.5 | 4.3 |
| **Total** | | **4,116.5 million** | **1196** | **161** |

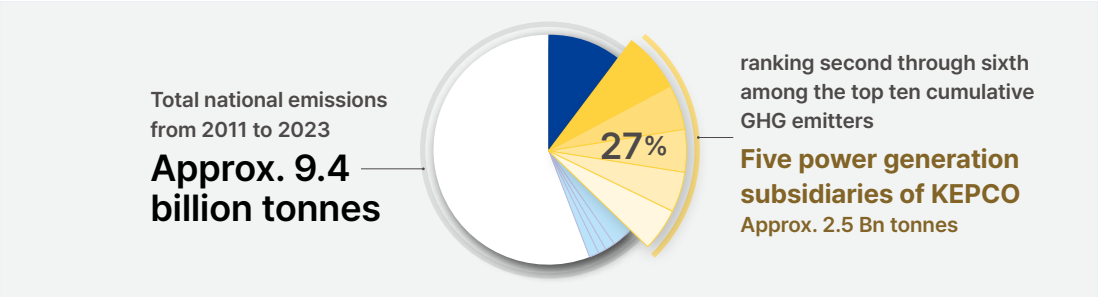
**[Figure 2]** Comparison of Cumulative GHG Emissions and Loss Contributions of South Korea's Top Ten Emitters (Including Five Subsidiaries of KEPCO)




POSCO tops the list. From 2011 to 2023, the giant steelmaker spewed out cumulative GHGs of approximately 968 million tonnes, incurring estimated climate-related losses of roughly USD 28.13 billion (approx. 38 trillion). This is the highest among all corporates analyzed. Steelmaking is notoriously carbon-intensive since it remains heavily reliant on coal-based blast furnace processes. POSCO has two major integrated steelworks in Pohang and Gwangyang that each release massive emissions and thereby pose severe climate and health risks to the surrounding region. This figure is not only a retrospective scorecard; it may also serve as a baseline for their transition strategy setting. That is because, looking ahead, a shift towards alternative production methods—such as hydrogen-based direct reduction of iron ($H_2$-DRI)—is inevitable in order to make deep emissions cuts.



It is also worth noting **the five power generation subsidiaries of KEPCO—KOEN, EWP, KOSPO, KOMIPO, and KOWEPO**—which rank second through sixth among the ten emitters. Together, these KEPCO Big Five emitted around 2.5 billion tonnes of GHGs over the same period, with associated climate losses estimated at USD 72.88 billion (approx. KRW 93 trillion). That is roughly 2.6 times the emissions from POSCO—the top single emitter—and accounts for about one-quarter of the combined total from the top ten corporate emitters. These utilities face a dual reality: they provide the essential public service of electricity supply, yet remain structurally dependent on carbon-intensive sources such as coal and liquefied natural gas (LNG).




Moreover, the distinctive nature of the power sector matters because emissions responsibility cascades down a sequential chain of accountability. The carbon emission factor (i.e., carbon intensity) of the electricity that a company consumes is determined by the mix of fuels—coal, LNG, and renewables—used in its generation. This shapes the company's Scope 2 indirect emissions. In simple terms, a power producer's fuel choices set off a *chain reaction* that influences the carbon footprint of other industries. In this regard, the responsibility of power generators extends beyond their own sector—or a few specific sectors—rippling throughout the entire industrial landscape.

Since the country's major power producers are state-owned, their emissions should be evaluated differently. They should not be assessed on the same footing as private firms. In a system where emissions-driven economic losses are ultimately borne by society at large, the public sector must go beyond merely meeting reduction quotas. It must serve both as a policy coordinator as well as a steward of climate-related financial risks. This mandate should feed directly into institutional debates on how to embed climate accountability and liability within the government's energy transition strategies, as well as into the ESG metrics and performance evaluation frameworks of state-owned corporations.

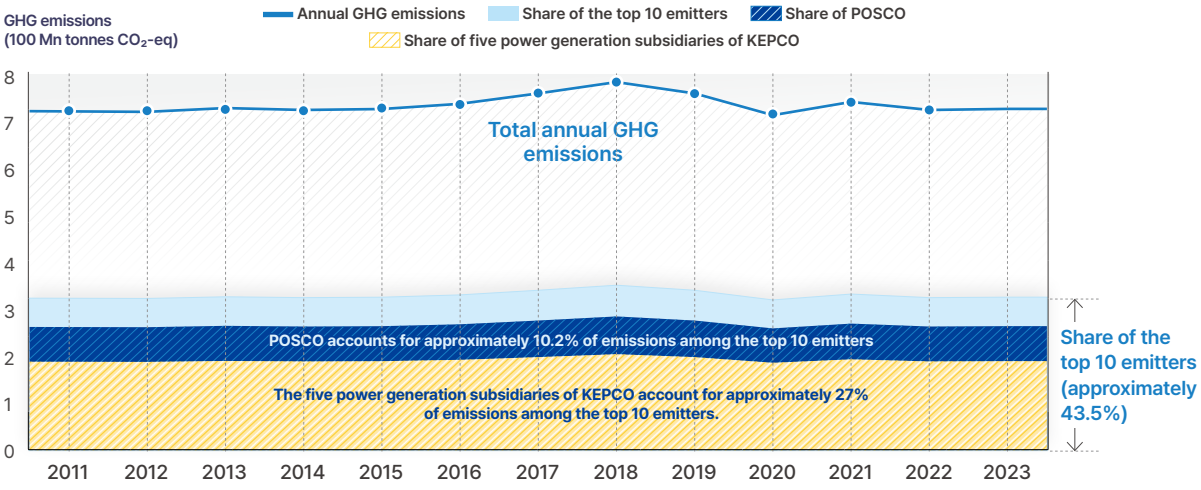
**[Table 4]** Cumulative GHG Emissions and Loss Contributions by South Korea's Top Ten Emitters (excluding KEPCO power-generation subsidiaries)

| Company (excl. KEPCO) | GHG Emissions 2011–2023 ($tCO_2$-eq) | Loss Contribution (USD 100 Mn) | Loss Contribution (KRW 1 Tn) |
|---|---|---|---|
| **POSCO** | 967.88 million | 281.3 | 37.9 |
| **Hyundai Steel** | 293.18 million | 85.2 | 11.5 |
| **Samsung Electronics** | 123.71 million | 35.9 | 4.8 |
| **Ssangyong C&E** | 112.75 million | 32.7 | 4.4 |
| **POSCO International** | 111.99 million | 32.5 | 4.3 |
| **S-Oil** | 110.57 million | 32.1 | 4.3 |
| **GS Caltex** | 167.4 million | 31 | 4.1 |
| **LG Chem** | 99.84 million | 29 | 3.9 |
| **SK Energy** | 94.56 million | 27.4 | 3.7 |
| **HD Hyundai Oilbank** | 91.22 million | 26.5 | 3.5 |
| **Total** | **2.11 billion** | **614** | **82** |

If the five KEPCO power-generation subsidiaries are removed from the top-ten list, their places are filled by four private refinery and petrochemical players—S-Oil, GS Caltex, SK Energy, and HD Hyundai Oilbank—together with the country's leading chemical firm, LG Chem. The nature of these new entries illustrates that major emitters are heavily concentrated in a few industries not only within the public sector but also across the private sphere. Together, these five private firms released around 500 million tonnes of GHGs during the study period, accounting for roughly six percent of the national total. The clustering of private companies in oil refining and petrochemicals underscores their central place in the architecture of climate liability.

These sectors share a common profile characterized by high costs for and steep technological hurdles to process conversion, structurally low abatement potential, and a sluggish pace of transition. The bulk of their emissions are process-related releases, stemming primarily from direct fossil fuel combustion. Thus, meaningful cuts in emissions cannot be achieved through incremental energy efficiency gains or a switch to renewables alone. They must be managed as priority targets across all policy levers—from climate policy to the emissions trading system (ETS) to financial risk assessments, among others.

**[Figure 3]** Comparison of Annual National Greenhouse Gas Emissions and Emissions from South Korea's Top Ten Emitters



# 5 Future Emissions Scenario Analysis and Loss Projections (2025-2050)

## 1 Definition of Scenarios

To analyze future GHG emissions scenarios and their climate impacts, this study used the Global Change Analysis Model (GCAM) v7.0—an Integrated Assessment Model (IAM). This model enables long-term assessment of climate change impacts by bringing together data from multiple domains—the energy system, the economy, agriculture and land use, water, and the climate—and by capturing the behavior of and interactions among those five interlinked domains.[17] In particular, this integrated assessment model can evaluate a broad range of climate mitigation and adaptation strategies, encompassing renewable energy deployment, technological shifts, policy and regulatory measures, and carbon pricing. One of the greatest strengths of this scenario-based simulator is its ability to test out a broad array of policies and technologies prior to real life applications. Moreover, GCAM divides the globe into 32 geopolitical regions for modeling macroeconomic and energy systems. A key advantage for this study is that South Korea is represented as a standalone region in GCAM's standard breakdown, indicating that the analysis of potential policy and regulatory impacts in the country is feasible. In addition, the model covers not only carbon dioxide ($CO_2$), but also a full suite of GHGs—including methane ($CH_4$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen oxides (NOx), and sulfur oxides (SOx)—providing a more complete picture of climate change impacts.[18] These capabilities made GCAM the model of choice for this study's assessment of how South Korea's climate polices may affect both its emissions trajectory and its economy.

This report uses the Current Policy (CurPol) and Net-Zero scenarios—outlined below—as the baseline scenarios and metrics for comparing the differences in South Korea's long-term GHG emissions trajectories and the resulting climate impacts, which will diverge depending on the country's future climate policy choices.

- **The Current Policy (CurPol) scenario** represents a business-as-usual (BAU) baseline that assumes no further changes to South Korea's existing climate and energy policies. In the absence of new GHG reduction targets and regulations, the current trajectory of GHG emissions continues, and present trends in technology and economic growth gain no additional momentum. This frozen-policy scenario serves as a benchmark for evaluating future policy directions and assessing the need for further climate countermeasures.

- **The Net-Zero scenario** charts a path to carbon neutrality by 2050 by balancing GHG emissions with carbon removals. This ambitious, forward-leaning pathway requires strong policy action and technological innovation, encompassing a range of mitigation strategies such as phasing out fossil-fuel power generation, expanding renewables, boosting energy efficiency, decarbonizing industrial processes, and electrifying transport. This decarbonization scenario also envisions faster structural transitions toward low-carbon practices across the economy and society, while building a comprehensive response framework that fosters sustainable growth and strengthens climate resilience through targeted policy incentives and robust institutional foundations.

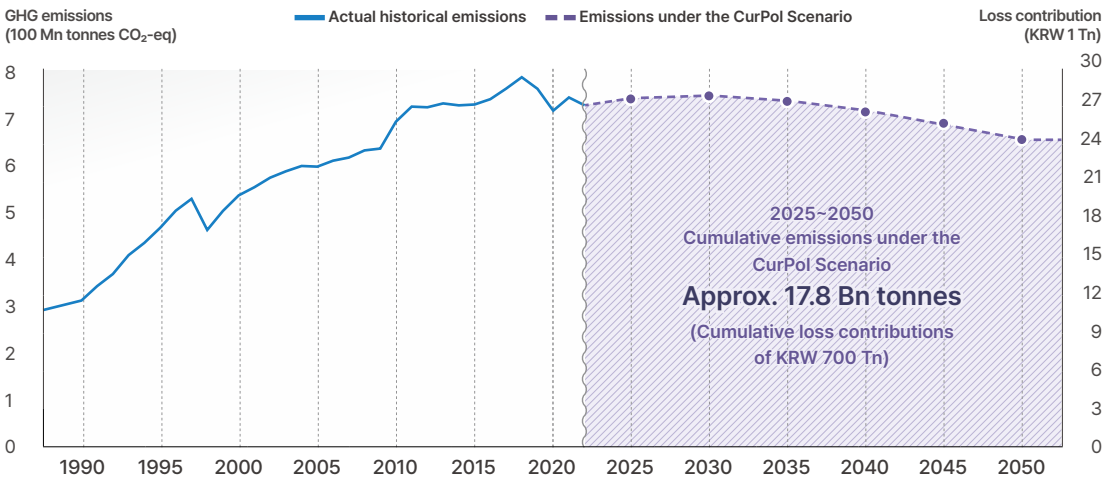
## 2 Loss Analysis by Scenario

According to SFOC's modeling, if South Korea stays the course under the CurPol scenario, GHG emissions will only edge down from about 740 million tonnes in 2025 to roughly 649 million tonnes in 2050, remaining stubbornly high. Over this quarter century, cumulative emissions are projected to total about 17.8 billion tonnes $CO_2$-eq. This translates into a staggering cumulative economic loss of roughly USD 518.9 billion (approx. KRW 700 trillion), based on the heatwave-related damage cost factor presented in the journal Nature's paper "Carbon majors and the scientific case for climate liability."

**[Table 5]** South Korea's 2025–2050 GHG Emissions and Economic Losses under the CurPol Scenario

| Year | Emissions under CurPol ($tCO_2$-eq) | Five-Year Cumulative Emissions ($tCO_2$-eq) | Loss Contribution by Year | | 2025–2050 Cumulative Loss Contribution |
|---|---|---|---|---|---|
| | | | (USD 100 Mn) | (KRW 1 Tn) | |
| **2025** | 739 million | - | 214 | 28 | - |
| **2030** | 745 million | 3.7 billion | 216 | 29 | - |
| **2035** | 730 million | 3.69 billion | 213 | 27 | - |
| **2040** | 713 million | 3.6 billion | 207 | 26 | - |
| **2045** | 683 million | 3.5 billion | 198 | 25 | - |
| **2050** | 649 million | 3.3 billion | 188 | 24 | - |
| **Cumulative Total** | - | **17.8 billion** | - | - | **Approx. USD 518.9 Bn (KRW 700 Tn)** |

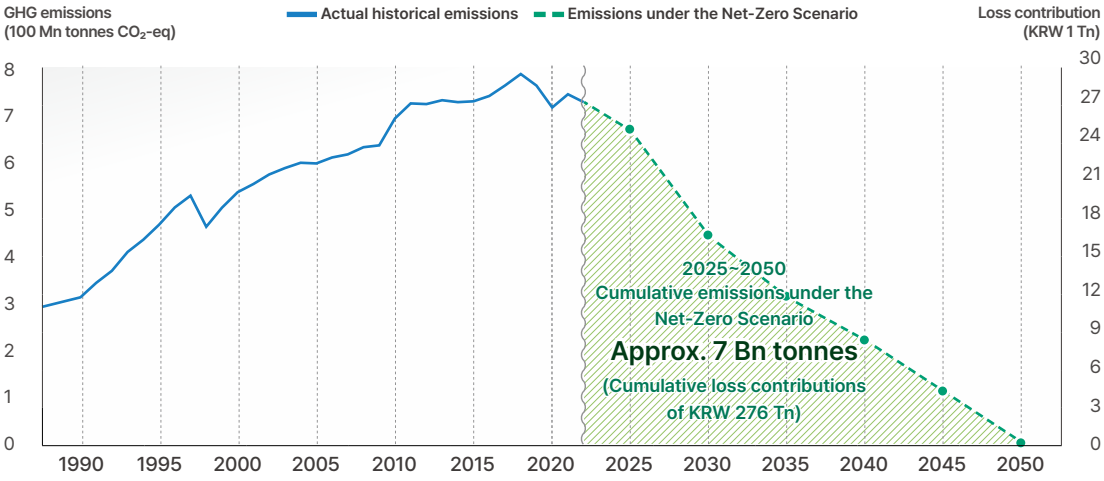
**[Figure 4]** Projected Trends in Greenhouse Gas Emissions and Economic Losses in South Korea under the CurPol Scenario (2025–2050)



**[Table 6]** South Korea's 2025–2050 GHG Emissions and Economic Losses under the Net-Zero Scenario

| Year | Emissions under CurPol ($tCO_2$-eq) | Five-Year Cumulative Emissions ($tCO_2$-eq) | Loss Contribution by Year | | 2025–2050 Cumulative Loss Contribution |
|---|---|---|---|---|---|
| | | | (USD 100 Mn) | (KRW 1 Tn) | |
| **2025** | 660 million | - | 193 | 26 | - |
| **2030** | 430 million | 2.8 billion | 127 | 17 | - |
| **2035** | 310 million | 1.8 billion | 90 | 12 | - |
| **2040** | 220 million | 1.3 billion | 63 | 8.5 | - |
| **2045** | 110 million | 810 million | 31 | 4 | - |
| **2050** | 0 | 270 million | 0 | 0 | - |
| **Cumulative Total** | **-** | **7.0 billion** | **-** | **-** | **Approx. USD 204.7 Bn (KRW 276 Tn)** |

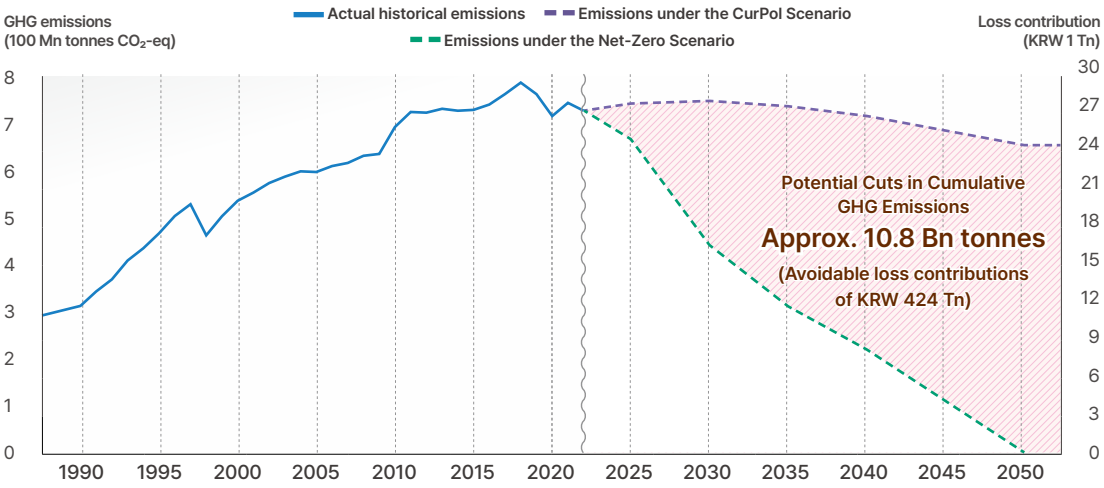
**[Figure 5]** Projected Trends in Greenhouse Gas Emissions and Economic Losses in South Korea under the Net-Zero Scenario (2025–2050)



**[Table 7]** Potential Cuts in Emissions and Economic Losses Enabled under the Net-Zero Scenario

| Year | Potential Cuts on Net-Zero Pathway ($tCO_2$-eq) | Potential 5-Year Cuts ($tCO_2$-eq) | Potential Savings in Economic Losses Enabled by Net-Zero Pathway |
|---|---|---|---|
| **2025** | 70 million | - | - |
| **2030** | 310 million | 900 million | - |
| **2035** | 420 million | 1.8 billion | - |
| **2040** | 490 million | 2.3 billion | - |
| **2045** | 570 million | 2.7 billion | - |
| **2050** | 649 million | 3.0 billion | - |
| **Cumulation** | - | **10.8 billion** | **Approx. USD 314.7 Bn (KRW 424 Tn)** |

**[Figure 6]** Analysis of Avoidable GHG Emissions and Economic Losses under the Net-Zero Scenario




Under the Net-Zero scenario, South Korea could avert roughly 10.8 billion tonnes of GHG emissions by 2050 compared to the less aspirational CurPol pathway. Applying the same $\alpha_{1990}$ heatwave-related damage coefficient from Callahan and Mankin (2025), these curtailed emissions correspond to an estimated USD 317.4 billion (approx. KRW 424 trillion) in avoided cumulative economic losses.

The magnitude of losses is striking because the figure only covers heatwave damage. If a wider spectrum of climate change-driven disasters—such as droughts, wildfires, torrential rains, floods, and typhoons—were taken into account, the total economic toll would be significantly higher. During recent years, South Korea have seen economic losses mount sharply from extreme weather—not only from heatwaves but also from crippling droughts, devastating wildfires, extreme downpours, and fierce typhoons.[19]

The per-tonne loss coefficient for heatwave damage ($\alpha_{1990}$) used in this analysis reflects historical climate damage patterns and past-to-present economic structures. As global warming escalates, both the heatwave coefficient and the associated loss estimates are expected to climb. Taken together, these factors make it almost certain that the actual cost of climate change will far exceed the figures projected in this report.

Beyond these more direct economic tolls, serious secondary impacts will cut far deeper—decreasing crop yields and quality, rising sea-surface temperatures, worsening air pollution, destabilizing prices and supply chains, inflating healthcare costs, diminishing labor productivity, swelling operation and maintenance (O&M) bills for infrastructure, and flooding coastal and urban areas—eroding both the quality of life and the national economy. They risk setting off destructive ripple effects, from widening social inequalities to deepening regional economic divides.

Ultimately, if the CurPol pathway persists, the country will face not only mounting fiscal losses but also growing socioeconomic uncertainty and disadvantage. These impacts will reverberate through public finances and saddle future generations with overwhelming economic and social burden. To tackle the climate crisis effectively, South Korea needs a far more ambitious policy stance than at present. Stronger and more systematic GHG reduction measures are not optional add-ons but an essential foundation for national sustainable growth and safeguarding the quality of life for all citizens.

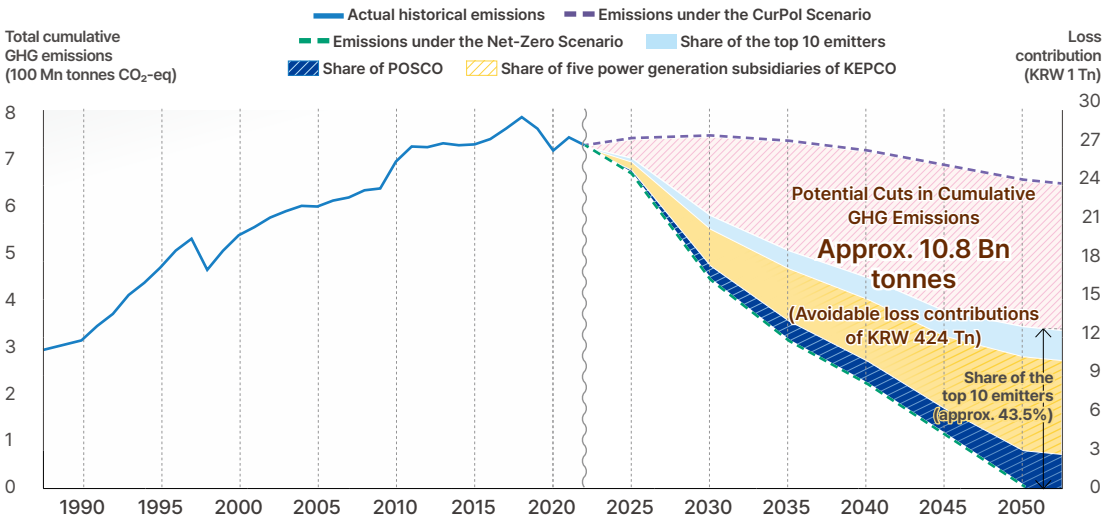
## 3 Emission Trend and Loss Projections by Company

This study projected the GHG emissions gaps between the Net-Zero and CurPol scenarios over the analysis period to quantify potential cumulative reductions. Applying the α1990 coefficient from Callahan and Mankin (2025), each company's share of future heatwave-driven losses and the losses that could be avoided along the more ambitious Net-Zero pathway were estimated.

In doing so, to attribute these projected emissions and losses to specific companies, this study used historical data on the top-ten emitters' shares of cumulative GHG emissions from 2011 to 2023.

Company-specific economic losses from heatwaves are projected under two contrasting pathways—one in which each company contributes to emissions reductions, and one in which it does not. The results provide a quantitative basis for assessing the extent to which individual firms, through their future emissions, may exacerbate social harm from climate change, such as extreme heat events. Ultimately, these figures can serve as practical grounds for debates on the scope and allocation of individual corporate climate liability and social responsibility.

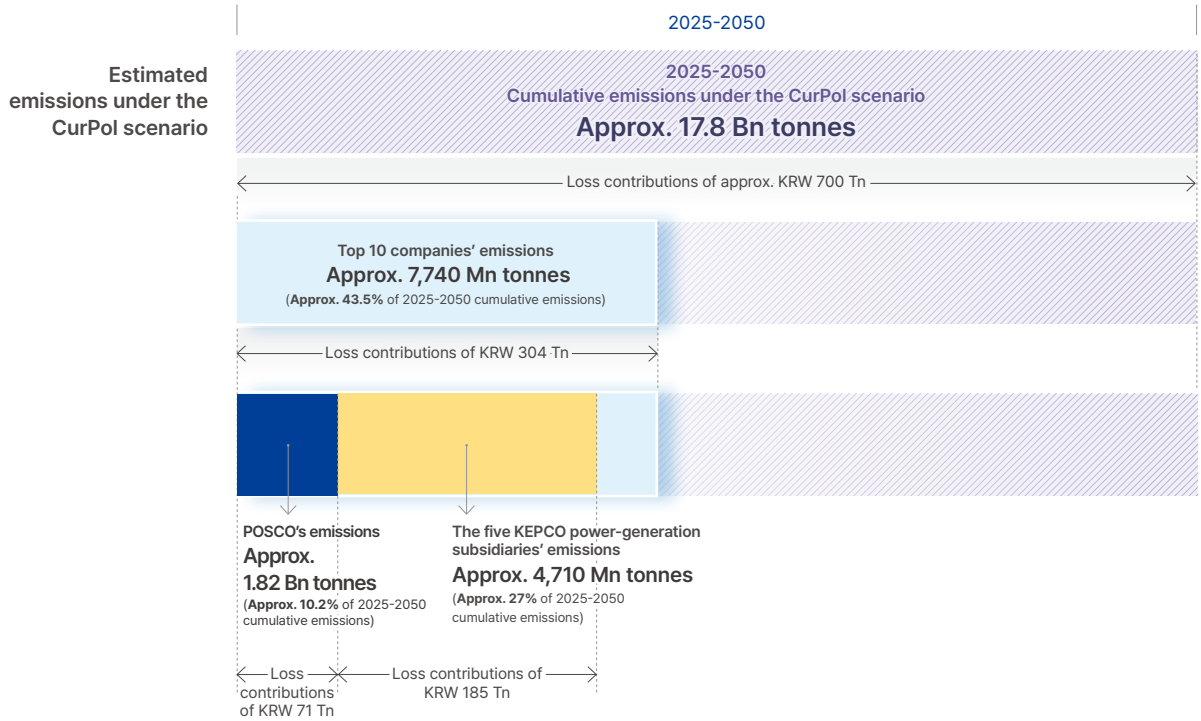
**[Figure 7]** Reduction Potential of GHG Emissions and Economic Losses of South Korea's Top Ten Emitters under the Net-Zero Scenario



**[Table 8]** 2025–2050 Cumulative Emissions and Losses Attributable to Ten South Korean Companies under the CurPol Scenario

| Company | | GHG Emissions 2025–2050 ($tCO_2$-eq) | Loss Contribution (USD) | Loss Contribution (KRW) |
|---|---|---|---|---|
| POSCO | | 1,820.94 million | 52.9 Bn | 71.46 |
| Including KEPCO's subsidiaries | KOEN | 1,217.52 million | 35.3 Bn | 47.78 |
| | EWP | 913.14million | 25.6 Bn | 35.83 |
| | KOSPO | 866.86 million | 252 Bn | 34.19 |
| | KOMIPO | 865.08 million | 251 Bn | 33.94 |
| | KOWEPO | 852.62 million | 24.7 Bn | 33.46 |
| Hyundai Steel | | 551.80 million | 16 Bn | 21.65 |
| Samsung Electronics | | 233.18 million | 6.77 Bn | 9.15 |
| Ssangyong C&E | | 211.82 million | 6.15 Bn | 8.31 |
| POSCO International | | 210.04 million | 6.1 Bn | 8.24 |
| **Total** | | **7,743 million** | **225.1 Bn** | **303.87 Tn** |

**[Figure 8]** Comparison and Analysis of Cumulative Emissions and Loss Contributions of South Korea's Top Ten Emitters under the CurPol Scenario, 2025–2050



The five KEPCO power-generation subsidiaries—KOEN, EWP, KOSPO, KOMIPO, and KOWEPO—collectively hold the largest share of emissions. This suggests that staying off the Net-Zero pathway will only invite massive social and financial burdens stemming from their outsized contributions to extreme climate-wrought losses. The non-carbon-neutral outlook is similarly grim for steelmakers POSCO and Hyundai Steel, and for refinery and petrochemical players such as S-Oil, GS Caltex, SK Energy, and HD Hyundai Oilbank, as well as for other private corporates including Samsung Electronics and LG Chem. Failure to achieve carbon neutrality could expose them to tens of trillions of Korean won in loss contributions and potential climate liabilities.

In short, the consequences of non-compliance with reduction obligations will reach beyond the emissions burden itself; they will expose each company to social costs alongside legal and financial liabilities arising from climate risks. These projections lay bare the scale of exposure individual companies may confront across diverse policy and institutional arenas such as the climate liability discourse, the emissions trading system (ETS), ESG reporting requirements, and financial risk assessments.

It is also worth noting that past and present emissions records are more than a historical ledger or a retrospective scorecard of GHG output—they are a critical benchmark in discussions of future climate damage and liability. If the CurPol pathway continues, these companies will remain primary contributors to the climate crisis, facing potential legal and financial liabilities and significant exposure to climate risks. By contrast, a shift to the Net-Zero trajectory can position them as constructive actors in mitigating climate risks while reducing their potential liabilities. Achieving corporate GHG reduction targets is not simply a regulatory compliance; it is an essential component of safeguarding national fiscal stability and addressing climate risk—an obligation that extends to both present and future generations.

# 6 A Rising Global Tide of Corporate Climate Liability

## 1 State Liability: Domestic Case Law and International Trends

To legally enshrine its ambition of achieving carbon neutrality by 2050, South Korea enacted the *Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis* in 2021.[20] However, in August 2024, this legal commitment to tackle the climate crisis was held to be unconstitutional by the Constitutional Court. In response to a youth-led petition, the unanimous ruling found that the historic act violated citizens' constitutional right to a healthy environment because its mid- and long-term emission reduction targets were inadequate.[21] Civil society hailed the decision as "a pointed rebuke of the state's neglect of its climate crisis responsibility under the guise of protecting corporate interests and economic growth" and called on lawmakers and executives to step up.[22] This stance was also affirmed by a recent advisory opinion of the International Court of Justice (ICJ). In July 2025, the World Court made it clear that *the obligations of mitigation, adaptation, cooperation, finance, and technological support are binding under international law and that member states owe a duty of due diligence to effectively supervise the emissions from domestic companies and individuals*.[23] Together, these rulings heighten state responsibility and underscore the mandate for governments worldwide to actively regulate corporate emissions. This, in turn, drives a marked expansion of corporate accountability. Given the risk that regulatory negligence may render states principal respondents in international accountability processes, governments should reinforce oversight of major corporate emitters by adopting stricter regulations, mandating emissions reductions, and expanding information disclosure. Perceiving this ICJ opinion as a *substantive legal risk*, investors, financial institutions, and other stakeholders are likely to raise the cost of capital for companies with inadequate mitigation roadmaps and press those reluctant actors to embed more concrete and clearer emissions-cut requirements in supply chain contracts. In effect, an international legal framework is now in place where states failing to properly manage corporate carbon majors risk facing state inaction liability.

## 2 Rising Corporate Carbon Liability and International Case Law

There have indeed been rulings recognizing state liability in climate cases worldwide, but no final court decision has yet affirmed corporate liability for climate impacts. The central stumbling block is causation: it is challenging to link a company's carbon emissions to specific harms. Yet the recent study by Callahan and Mankin (2025) breaks new ground by introducing a methodology that clears that hurdle, charting an empirical pathway to demonstrate the likelihood of corporate carbon liability. Building on their framework, this report applies the methodology to South Korea to estimate potential corporate liability and the magnitude of associated losses.

In recent years, climate litigation targeting corporations has been gaining momentum abroad. In 2021, the District Court of The Hague in the Netherlands handed down a landmark ruling in a case brought by Milieudefensie and other civil society groups against Royal Dutch Shell plc, ordering the entire Shell group to cut its net emissions by 45 percent from 2019 levels by 2030. Shell appealed—successfully. In November 2024, the 45-percent cut order was overturned by the Hague Court of Appeal, which held to the effect that while companies like Shell do have a general duty of care to counter dangerous climate change, they cannot be ordered to achieve a fixed percentage reduction. Noting states' obligations to safeguard the right to life and the right to privacy under the European Convention on Human Rights (Articles 2 and 8), however, the Appeal Court derived the *social duty of care* from the Dutch Civil Code and held that companies like Shell—whose products contribute to the climate problem—are expected to help avert dangerous climate harm.[24]

Germany saw another climate lawsuit in which the claimant—Saúl Luciano Lliuya, a Peruvian farmer—sued the German energy giant RWE. In May 2025, the Higher Regional Court of Hamm dismissed his claim on the grounds that the risk of a glacial lake outburst is a *mere one percent over the next 30 years* and posed no specific threat to his property. Yet in the same breath, the court affirmed a watershed doctrine: *companies may indeed be held liable for the consequences of their own GHG emissions*.[25] Supporters of the claimant welcomed the decision as a historic milestone, and the NGO Germanwatch regards it as a key that could open the door to similar actions worldwide.[26]

Though neither the Shell nor the RWE lawsuit has ended in an outright victory for the claimants—the former still pending before the highest court in the Netherlands,

and the latter already finalized—both have shifted the legal landscape, cracking open the possibility of imposing legal liability on corporate carbon majors. Together, they illustrate how far climate litigation can push the horizon for the corporate liability discourse. No court has yet imposed specific binding reduction targets or awarded damages. However, the trend is unmistakable: the scope of corporate liability for carbon emissions is expanding, grounded on the touchstones of human rights, environmental rights, and the right to a healthy environment.

# 7 Conclusion: Addressing the Climate Crisis through Corporate Liability

The climate crisis—once considered a distant threat of the future—is now our biting reality. Unprecedented heatwaves, torrential rains, droughts, and rising seas are resulting in devastating social and economic consequences. A critical question arises: *who is responsible for the damage?* Until recently, responsibility has been discussed primarily at the national level, with governments taking the lead in setting reduction targets and running reporting frameworks under international agreements. Yet, responsibility is now moving past the national level to zoom in on corporations. Science can trace GHG emissions from core business activities—such as investment, production, and sales—to measurable climate impacts including extreme heat events. These are increasingly being translated into quantifiable *carbon liability*, reshaping the legal and policy landscape. Callahan and Mankin (2025), published in the journal Nature, laid the scientific groundwork for this shift. Building on their methodology, this study quantified the loss contributions of South Korea's major corporate emitters and, through an Integrated Assessment Model (IAM), projected the economic losses that could unfold under diverging national policy pathways.

The report finds that the carbon neutrality pathway could save South Korea an estimated KRW 424 trillion in economic losses. If efforts to reduce carbon emissions are insufficient, the associated social costs and damages will be borne by the public and future generations. By promptly implementing GHG reduction policies and structural transitions, it is possible to reduce future social costs and open a pathway to ensuring the sustainability of the nation as a whole. The climate crisis has outgrown the realm of negotiations and lofty declarations. Addressing it demands practical liability sharing and concrete action.

We now stand at a point where it is necessary to examine and address the question of who bears responsibility for the climate crisis and to what extent. South Korea, too, must anchor the principle of carbon liability in law and policy and translate it into enforceable, practical measures to actively respond to the climate crisis. Only then can both the state and its businesses emerge as genuine agents of climate transition

and earn the trust of the international community. This goes beyond fair burden-sharing and preventive measures to mitigate future harm from climate disasters. It is also about fulfilling a substantive duty of the present and laying the foundation for the future. Now South Korea's government and businesses have to answer the climate crisis—by preemptively responding to GHG emissions and building a credible reduction framework that meets the urgency of the moment.

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